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Pilot Scale HCl Control by Dry Alkaline Injection for Emissions from Refuse Incinerators

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PILOT SCALE HCL CONTROL BY DRY ALKALINE INJECTION FOR EMISSIONS FROM REFUSE INCINERATORS

NOVEMBER 8, 1988

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Disclaimer

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ABSTRACT:

A 500 acfm pilot scale HCl control system utilizing dry powdered sorbent was tested at the University of Washington. Powdered alkaline reagents including sodium bicarbonate and calcium hydroxide were injected into boiler flue gas spiked with hydrogen chloride gas. The acid gas reacts with the injected sorbent in a 20 inch diameter by 26 foot high vertical, down-flow vessel. HCl removal efficiency was measured as a function of sorbent stoichiometry, gas residence time in reactor and reaction temperature.

PURPOSE:

Several studies have been conducted, including one by Ken Fellows and Mike Pilat at the University of Washington, measuring HCl removal efficiency by dry powdered sorbents in fixed beds. These studies have examined the reaction mechanics of acid gas sorption where gases are continuously passed through a static sorbent layer. This may be most applicable to the case where acid gas sorption is limited to that occurring on the surface of sorbent coated fabric filters (baghouses).

Another method of removing the HCl in an exhaust gas stream is to directly inject finely divided sorbent particles into the gas stream upstream from particulate collection equipment, allowing enough time for the HCl to react with the sorbent in the duct. This study proposed to provide data on HCl removal from a simulated incinerator exhaust stream as a function of the in-duct reaction/residence time, the reaction temperature and the sorbent to gas ratio.

The dry sorbert injection method is now in use in only nine municipal incinerator installations worldwide. Data on the problems associated with dry sorbent injection is not yet abundant. This study provides the researcher with hands-on experience working with such a system on a pilot scale. It further allows the opportunity to develop or refine sampling techniques used to determine the in-duct HCl sorption.

A third goal of this ongoing research will be to compare HCl removal efficiency obtained using dry sorbent injection to that observed when using slurried sorbent injection. The latter technique has been more extensively studied and is often applied to sulfur dioxide removal at fossil fuel fired electric generating installations.

APPLICABILITY:

Dry sorbent injection for acid gas control offers several application advantages to slurried sorbent techniques. The most apparent is the ability of a dry sorbent system to adjust to changing acid concentrations quickly. Slurried sorbent addition adds water which quenches the gas as it evaporates. Exhaust gas temperature must be kept above dewpoint in order to maintain the sorption reaction as well as avoid condensation and attendant corrosion problems. The sorbent addition rate therefore cannot be significantly changed without first changing the slurry concentration, which increases response time dramatically. Dry sorbent injection rates can be continuously varied in response to changing HCl load without affecting the temperature of the exhaust gas. This may be particularly important to small hospital waste incinerator installations where waste flows and consequently exhaust parameters are least uniform.

Another promising application is to incinerators with existing particulate control equipment. Many such units are faced with new HCl emission limits which requiring supplemental control measures. This is beyond the particulate removal equipment originally approved and installed. Where dry fabric filtration is used for particulate control, in-duct dry sorbent injection can be added without substantial modification. Existing baghouses can be employed and high maintenance slurrying equipment is not required.

2 STAGE SORPTION REACTION:

Upon injection into a hot (>250° F) gas stream sodium bicarbonate gives up one hydrogen atom becoming sodium carbonate. Although chemically identical to mined sodium carbonate, the decomposed sorbent is much more porous, owing to the "popcorn" effect induced by rapidly evolving hydrogen gas. This increased porosity yields a much higher surface area per unit mass upon which sorption will occur.

Calcination:

$$2\ NaHCO_3 \xrightarrow{heat} Na_2CO_3 + H_2O + CO_2$$

The sodium carbonate thus produced reacts with HCl forming sodium chloride, water and carbon dioxide as follows.

Conversion:

$$2\ HCl + Na_2CO_3 \longrightarrow 2\ NaCl + H_2O + CO_2$$

LIME SORPTION REACTION

Lime (Calcium Hydroxide) does not decompose at normal exhaust gas temperatures, instead undergoing a simpler single stage reaction with Hydrogen Chloride to form Calcium Chloride.

$$2\ HCl + Ca(OH)_2 \longrightarrow CaCl_2 + 2\ H_2O$$

APPARATUS:

The equipment used in this experiment is detailed in Figures 1 and 2. It consisted of:

(1) A flue gas source (the #5 Power boiler at the University of Washington Powerhouse) to which dry HCl gas was added at a measured rate. Two exhaust lines were provided, one each upstream and downstream of the air preheater. These two lines were mixed using butterfly valves to achieve the desired gas temperature. Total flow rate was approximately 500 ACFM and 400° F.

(2) A reaction vessel, 26 feet high by 20 inches in diameter. The vessel was vertically oriented with horizontal gas inlet at the top. Flue gas was pulled through the reaction chamber by a downstream fan at a rate determined by the downstream damper setting. This provided an adjustable gas residence/reaction time for the experiment. The vessel was equipped with three 4 inch diameter sampling ports downstream of the sorbent injector and one port upstream. Two of the downstream ports and the single upstream port were used in this experiment.

(3) A dry sorbent feeder. This device was custom fabricated for earlier sulfur dioxide removal efficiency experiments conducted at the University. It included a rotating brush in a hopper pushing sorbent powder over a fixed screen. The powder passing the screen dropped via a funnel to an open flexible plastic tube to the reaction vessel. Flow through the tube was induced by the 4 inch w.g. vacuum in the vessel. Sorbent feed rate was measured before and after each experiment by removing the funnel and collecting the falling powder in a plastic bag over a fixed time interval and then measuring the collected mass.

(4) Three discrete sampling trains. Each train consisted of a heated teflon sample line leading to 4 midget impingers in an ice bath, followed by a adjustable vacuum pump and a calibrated dry gas meter. The first two impingers contained 20 ml of deionized water. The third impinger was dry and the fourth contained dessicant silica gel. Downstream from the dry gas meters, Mylar gas sampling bags captured the sample gas for O_2 analysis at the completion of each test.

It is important to isolate the sample gas from continued reaction with the sorbent after it has been removed from the reaction vessel. For this, Pilat Mark 3 or 5 cascade impactors were used on the two downstream sample trains to remove any entrained particulate. The button hook sampling nozzle was pointed downstream to the gas flow to further reduce particulate mass reaching the impactor.

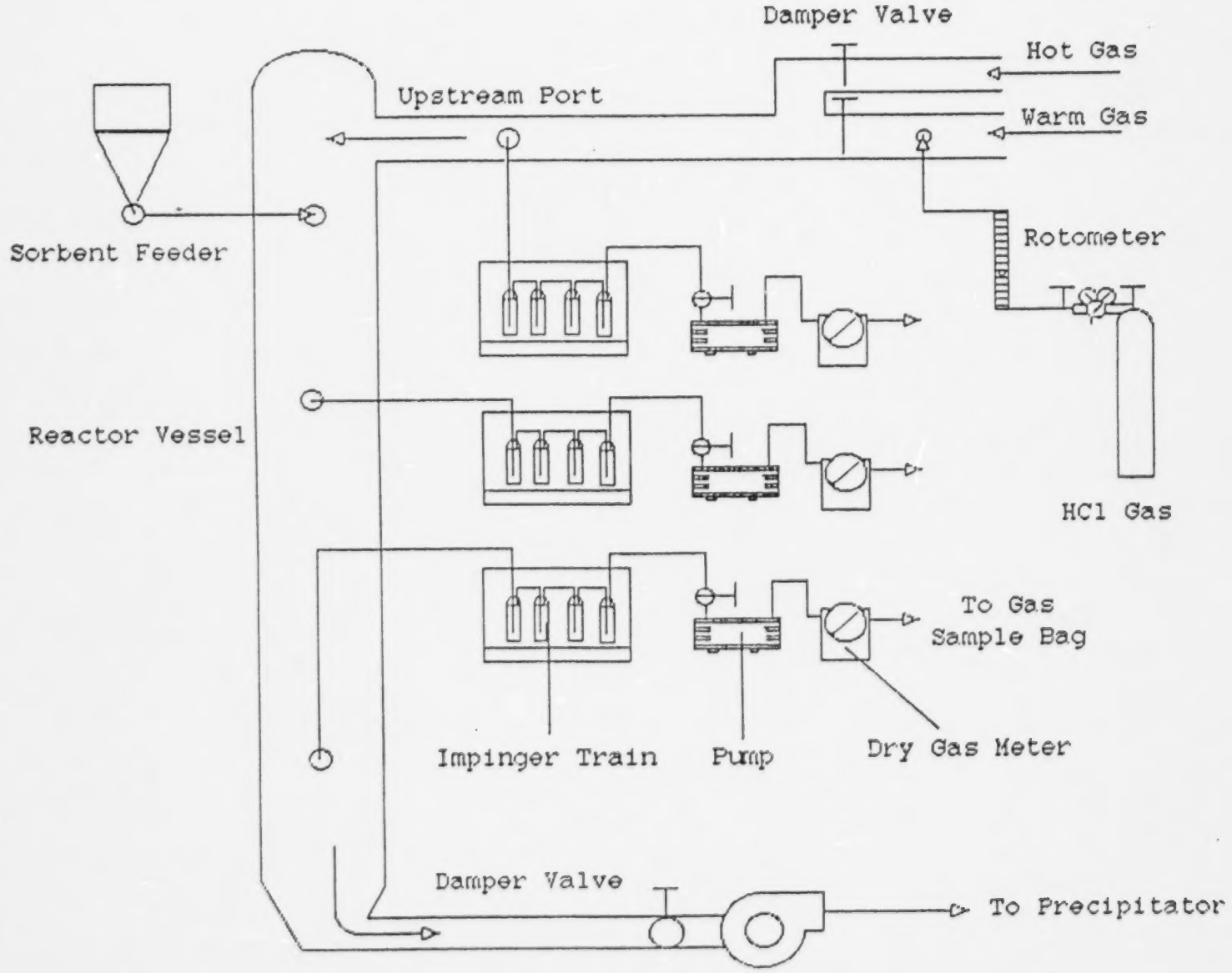

Damper Valve
Hot Gas
Upstream Port
Warm Gas
Sorbent Feeder
Rotometer
Reactor Vessel
HCl Gas
To Gas
Sample Bag
Impinger Train
Pump
Dry Gas Meter
Damper Valve
To Precipitator

Figure 1

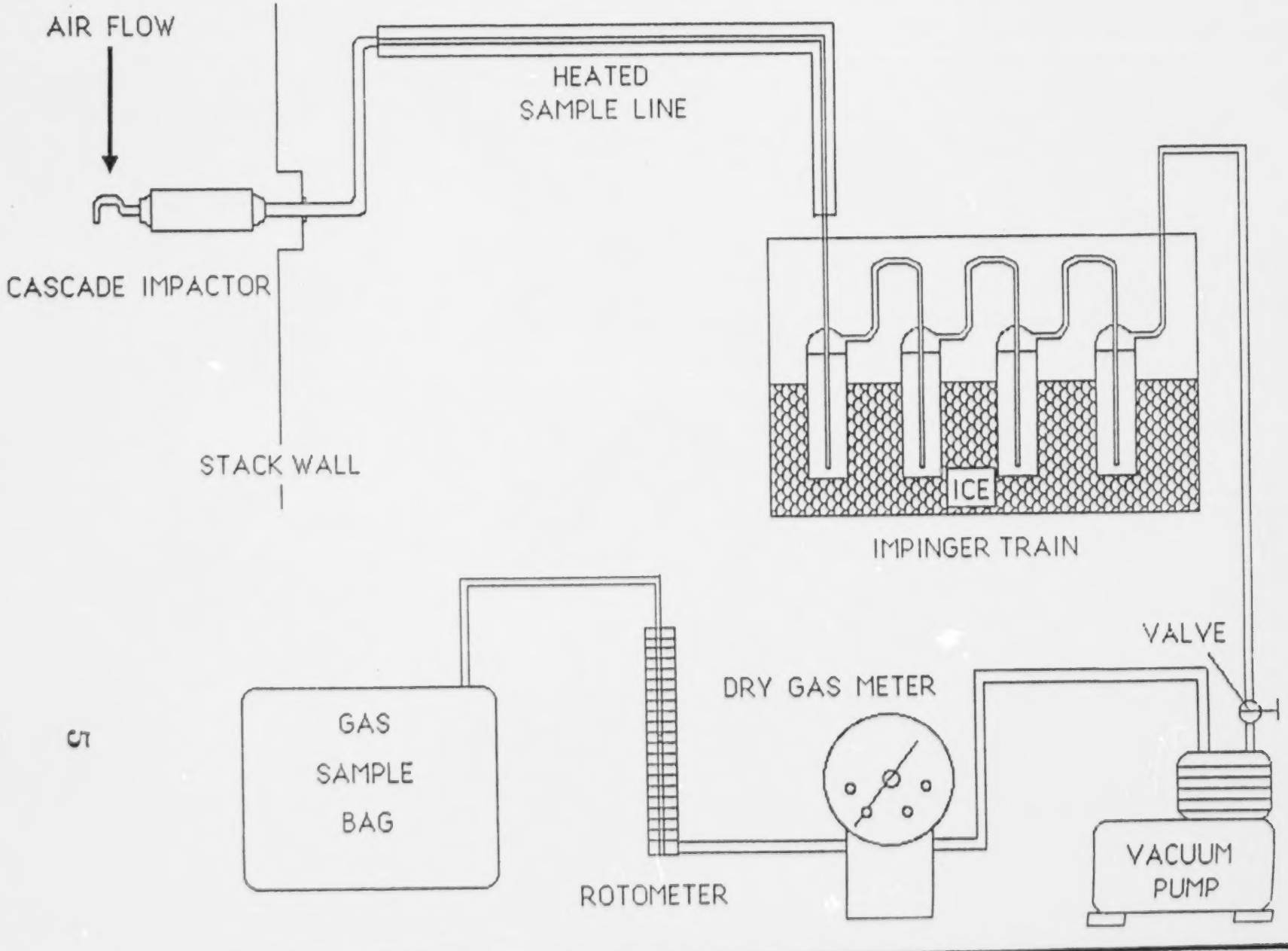

AIR FLOW
HEATED
SAMPLE LINE
CASCADE IMPACTOR
STACK WALL
ICE
IMPINGER TRAIN
VALVE
DRY GAS METER
GAS
SAMPLE
BAG
ROTOMETER
VACUUM
PUMP

Figure 2

PROCEDURE:

Gas flow to the system was first adjusted upstream for temperature. The reaction vessel was allowed to equilibrate. During this time measurements of the gas temperature and velocity were made upstream and downstream of the sorbent injection point. The impingers were prepared and a leak check made to insure the integrity of the sampling train. Once the gas flowing through the reaction vessel had reached the desired temperature throughout, ± 20° F., the flow velocity was adjusted by partially closing the downstream damper. The velocity upstream from the sorbent injector was again checked using a pitot tube and magnehelic gauge to make sure the volumetric flow rate was correct.

Dry Hydrogen Chloride gas was injected through a rotometer approximately 8 feet upstream from the first sampling point. This allowed complete mixing of the HCl with the flue gas prior to the upstream HCl concentration measurement. Flow through the rotometer was allowed to stabilize prior to starting the tests.

Simultaneous samples were taken from the upstream and two downstream sampling points using the sampling trains described above. The samples were taken over a 10 minute period during which sorbent was continuously fed through the metering system into the reactor. Sample gas flow rates were adjusted on each train at one minute intervals against the dry gas meter totals to maintain a 1 liter per minute average. HCl gas flow was monitored throughout the test.

Sorbent feed was visually monitored and carefully maintained throughout each test to prevent plugging at the bottom of the feed funnel and in the flexible plastic feed tube. By careful and continuous attention to the feeder operation it was possible to maintain sorbent feed at a relatively constant rate ± 10% .

The lines to the upstream and second downstream impingers were electrically heated to the highest temperature possible without deformation of the teflon tubing. This point was found through trial and error and was not correlated to a specific gas temperature. Early tests found severely diminished flows after several minutes of run time due to softening and constriction of the teflon liners at bends and joints. Lower heater settings resulted in noticeable condensation in the lines near the junction with the first impinger. The line to the first downstream sampling train was not heated due to the lack of operable heated sampling lines, but was insulated and shortened to approximately 18 inches total to avoid condensation as far as possible.

Upon completion of the sample run the lines were broken and rinsed to recover condensed water. This rinse was found to contain much higher concentrations of HCl per volume than the impingers and was therefore critical to the accurate determination of concentrations in the reactor.

The impingers were then returned to the lab and weighed in-toto to determine the mass of water collected. This was used later in correcting the exhaust gas to standard conditions. The impinger water and rinses were combined and analyzed to get total HCl concentrations at each sampling point, thereby allowing calculation of the HCl removal efficiency.

Three separate analysis methods were attempted and two were found to give consistent HCl concentrations.

Ion Chromatography:

Ion chromatographic analysis of the combined impinger and rinse solutions was performed by Suzanne Denise Connor at the University of Washington Chemistry Department. This method yields Cl^- concentration directly in mg/Liter. By carefully measuring the total volume of the impinger and rinse solution, the total mass of Cl^- can be calculated for each point and the HCl removal efficiency determined. Ion Chromatography results were found to be the most consistent of the three tested. It is also the method specified by the Puget Sound Air Pollution Control Agency for HCl testing in incinerator exhaust streams. With appropriate calibration standards it yielded accurate results over a solution concentration range of 0-70 ppmv.

Chloride Specific Ion Electrode:

The ion electrode technique was employed to give Chloride concentrations immediately after each test run. Its major advantage is the ease and speed of use. An Orion Research model 9417B Chloride specific electrode was used with an analog voltmeter to measure the electrical potential between the impinger solutions and a standard reference. The voltmeter readout was converted to molarity according to:

$$\text{Molarity} = 10^{-(\Delta E/S)}$$

Where ΔE is the voltage potential and

S is slope of the electrode response curve, which is temperature dependent and averages between 54 and 60 mV per decade at lab temperature.

mg/Liter is then computed from molarity according to:

mg/Liter = Molarity * Chlorine Atomic Weight

Total mass of captured Cl^- is then calculated as before. This method also yielded reproducable and relatively consistent results, although difficulty in accurately reading the coarsely divided analog scale made this technique less reliable than Ion Chromatography. Results using this method are reported only where I.C. results were unavailable.

Silver Nitrate Titration:

This method is the standard Mohr Silver Nitrate titration using Potassium Chromate as an indicator. Because of the potential carcinogenicity of the indicator disposal of the waste solutions posed special concern. A second problem was the difficult titration endpoint. After several attempts by the author a repeatability of only ± 10% was possible on known lab standard solutions. None of the data reported here resulted from this analytical technique.

Once the solutions were analyzed for Cl^- concentration a spreadsheet program was used to reduce the gas flow data to standard conditions and calculate and graph the removal efficiencies.

PROBLEMS ENCOUNTERED:

The regulator on the HCl gas bottle was specified for extreme corrosion duty. Nonetheless significant corrosion of the internal valves occurred leading to unsteady HCl flows toward the end of the experimental period. Fluctuations as high as 50% were noted, requiring constant operator attention to trim. Since the in-duct concentrations of HCl were averaged over the 10 minute sampling interval the effect of changing HCl concentrations on sorption efficiency is masked.

Under the best of conditions the sorbent feed rate in mass per unit time was maintained at only ± 10% over the 10 minute sampling interval. This was due primarily to the design of the sorbent feeder, and to some extent to the skill of the feeder operator. Sodium bicarbonate was particularly difficult to feed consistently. It tended to agglomerated at the base of the fixed screen and in the funnel forming larger chunks. These larger pieces would sometimes lodge in the feed tube or hang up on the funnel surface, dropping at random intervals into the injector. The bicarbonate also exhibited a marked tendency to adhere to the inside of the feeder and injector tube. The level of sorbent in the feed hopper was also found to directly influence the feed rate with all other conditions being stable.

The sorbent injection point consisted of an open tube oriented (more or less) upward toward the down flowing gas. Since there was no distribution nozzle and the driving force behind the injector was only a 4 inch w.g. vacuum, and given the "chunky" nature of some of the incoming sodium bicarbonate, it is not likely the sorbent was well dispersed upon entry. Large particle fallout on the inside of the reaction vessel was observed but not quantified. Other full scale dry sorbent systems inject into a higher velocity, turbulent gas stream to effect "atomization" of the sorbent powder.

The lack of flow straightening vanes or distribution baffles in the reactor, coupled with the imprecise orientation of the injector pipe led to non-uniform distribution of sorbent within the reactor. This was confirmed by particulate sampling during sorbent injection which found as much as twice the sorbent concentration on one side of the duct as on the other.

On several test runs condensation was noted in the heated sampling lines in the vicinity of the impingers. An effort was made to capture this condensate upon completion of the test run, since the condensed water readily absorbs HCl from the sample stream. Due to the orientation of the lower sample line (running uphill from the port to the impingers) some of the condensate was likely lost back to the duct before it could be recovered. This would bias the reported collection efficiency of the reactor and casts suspicion on the quality of the data recovered.

RESULTS:

Testing with lime as the sorbent was interrupted after only two trials. During those tests problems with the sorbent feeder yielded meaningless stoichiometric ratios and collection efficiencies. The data from those trial is not presented here.

More complete data was obtained from the tests using sodium bicarbonate. The data presented in Figure 3 indicate the majority of HCl is removed during the first second of exposure in the reactor. Additional, but decreasing removal was noted between the first and second sampling points. This is consistent with the expected decreasing reaction rate as the amount of sorbent available and the remaining HCl in the gas stream diminish.

The reaction rate constant is obtained by plotting the natural log of the HCl concentration remaining at each interval versus exposure time. This graph is given as Figure 4. and yields a linear plot with the slope equal to the reaction rate coefficient of 1 to 1.2 sec^{-1}.

The data for all residence times and stoichiometric ratios taken collectively can be averaged to a single line with a linear fit R^2 value of 0.93. Removal efficiencies over 95% are predicted after 4 seconds reaction time using approximately 1.8:1 sorbent to gas ratios.

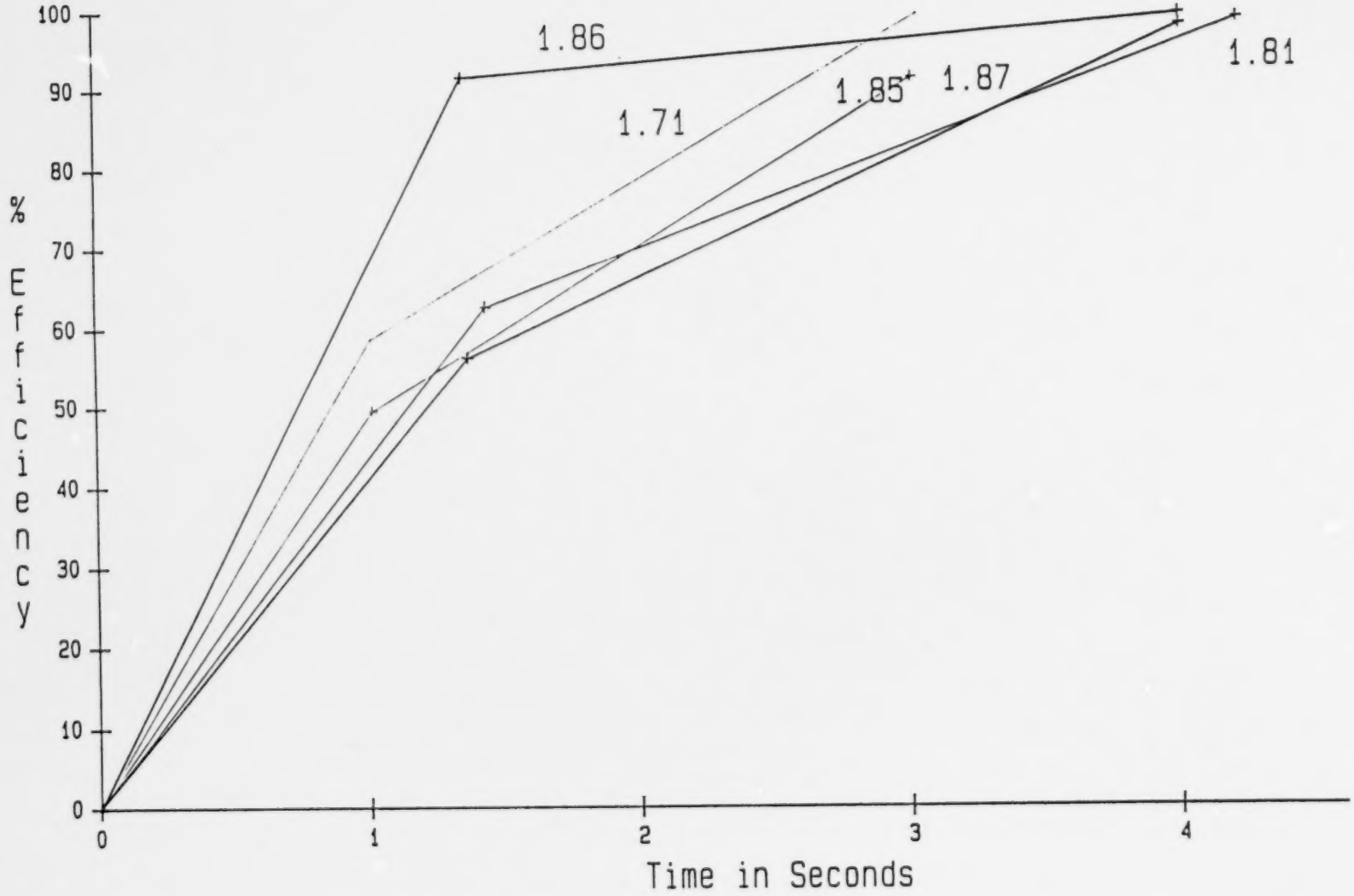

100
90
80
70
60
50
40
30
20
10
0
% Efficiency
0
1
2
3
4
Time in Seconds
1.86
1.71
1.85
1.87
1.81

Figure 3

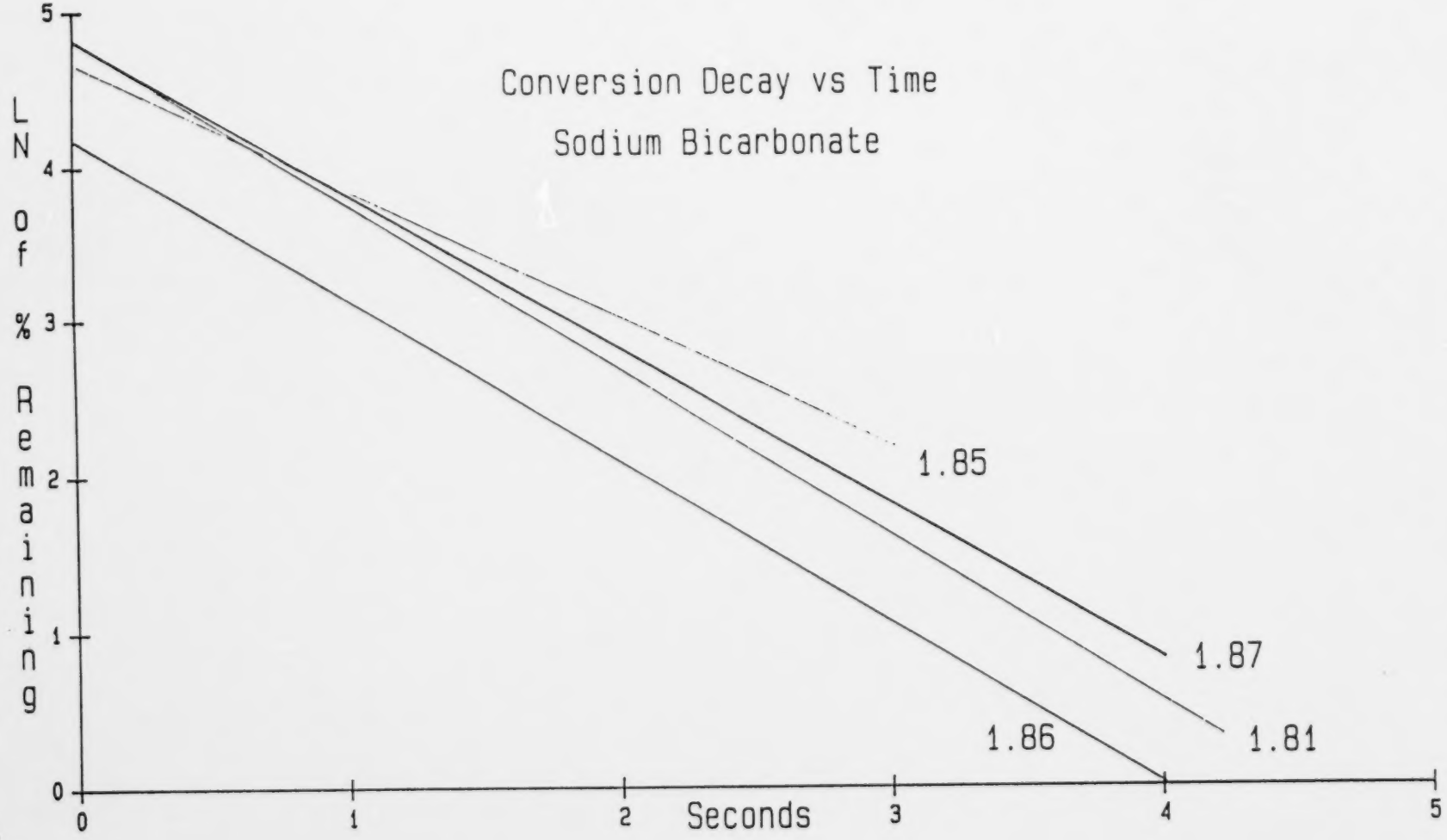

Conversion Decay vs Time
Sodium Bicarbonate
LN of % Remaining
5
4
3
2
1
0
0
1
2
Seconds
3
4
5
1.85
1.87
1.81
1.86

Figure 4

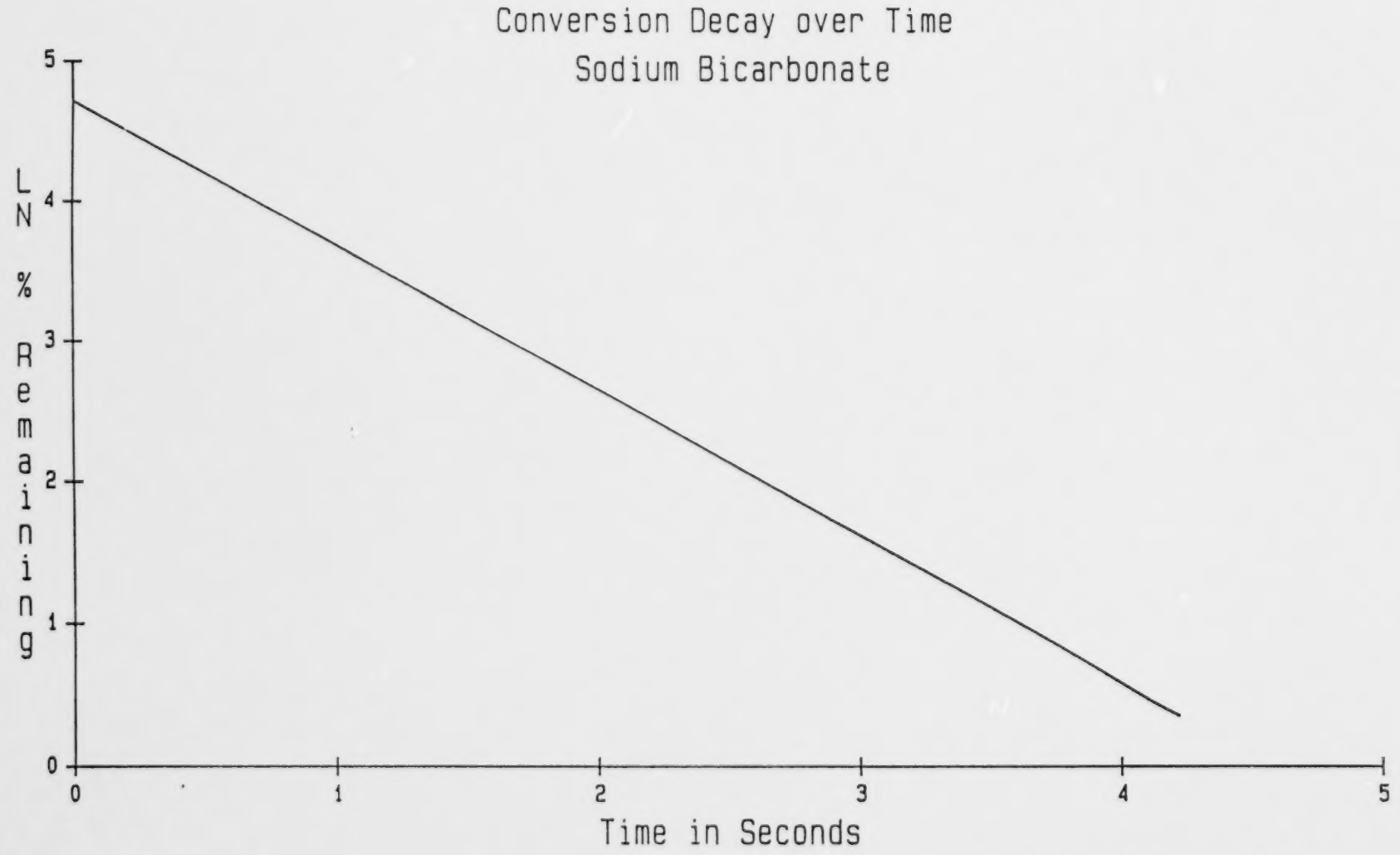

Conversion Decay over Time
Sodium Bicarbonate
LN % Remaining
0
1
2
3
4
5
Time in Seconds

Figure 5

SUGGESTED IMPROVEMENTS:

Sorbent Injection:

In order to provide a uniform suspension of sorbent prior to injection, an alternative feeder system has been designed (Figure 6). Sorbent can be metered into the large recirculating volume at controlled rates providing a stable high density suspension. This recirculating suspension can be tapped and educted into the reaction vessel at a controlled rate by opening an air inlet valve on the vacuum side of the blower.

Sampling Procedure:

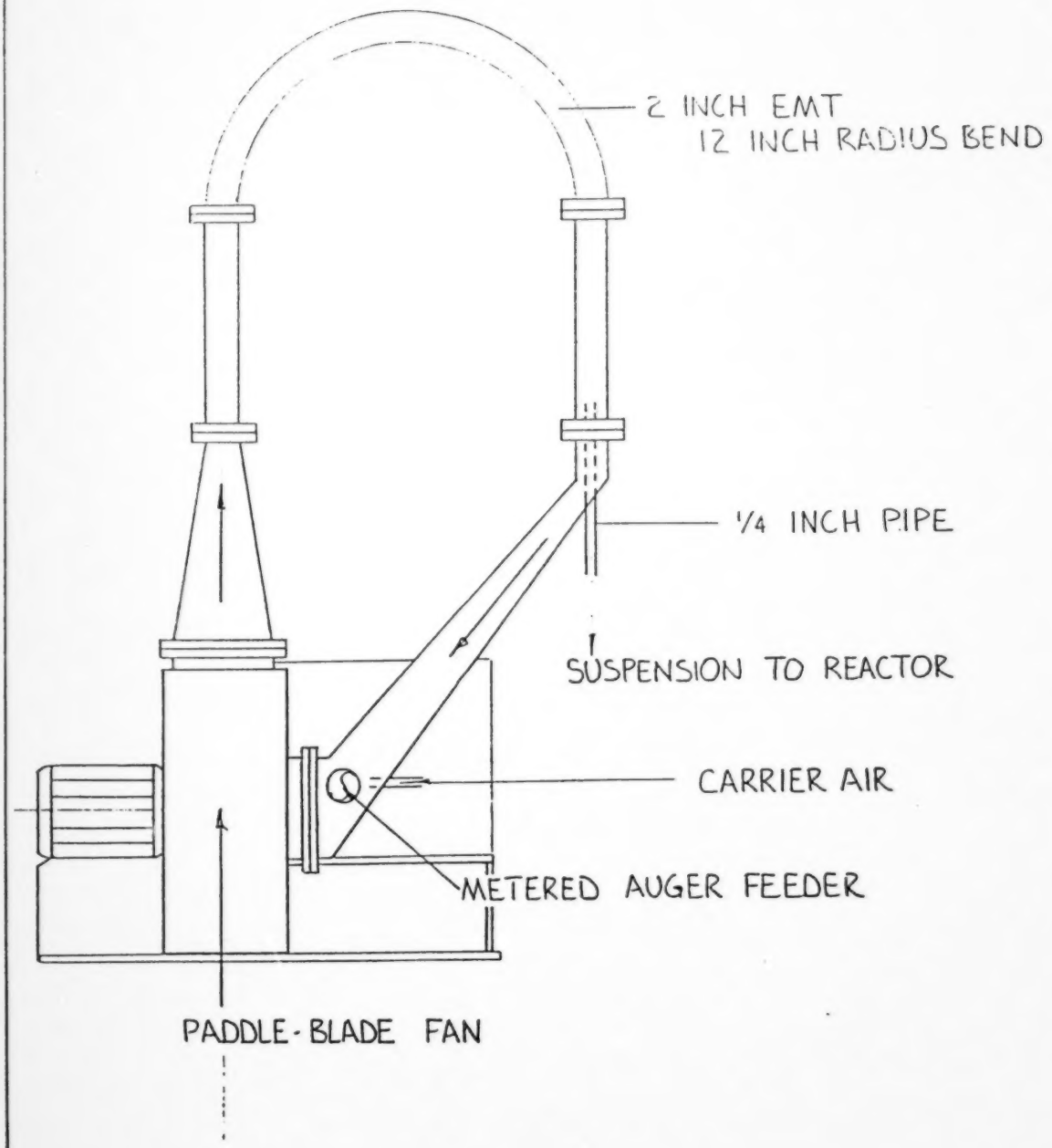
Two changes should be made in the sampling procedure. The first is to shorten and relocate sample lines to prevent condensation from drooling back into the reaction duct. This may have been the major source of error in this experiment to date.

A second suggestion would be to place an impinger filled with concentrated sulfuric acid directly at the sample port to dessicate the sample gas prior to reaching the sampling impingers. This would make analysis of the water content of the gas stream slightly more difficult. This is not seen as a problem at this test installation however, since the water content of the natural gas fired boiler exhaust is relatively consistent.

Apparatus:

As mentioned above, the lack of uniform gas flow within the reaction vessel makes analysis of collection efficiency versus residence time very difficult. Baffles and flow straightening vanes should be to installed in the reactor to provide uniform flow. The sorbent injection point could be located immediately below this point to allow injection into a predictable gas flow.

Figure 6


2 INCH EMT
12 INCH RADIUS BEND
1/4 INCH PIPE
SUSPENSION TO REACTOR
CARRIER AIR
METERED AUGER FEEDER
PADDLE-BLADE FAN

TRIP REPORT

Greater Vancouver Regional District
Burnaby Incinerator
December 15, 1988

The Burnaby incinerator is owned by the Greater Vancouver Regional District (GVRD) a federation of all municipalities and electoral areas in Greater Vancouver. This District is responsible for sewage treatment and disposal, water supply and distribution, regional parks, hospital planning as well as air pollution control and solid waste disposal. It is operated by Montenay Inc.. The tour was conducted by Mr. Ken Boatwright, (604) 521-1025. The Plant Manager is Mr. Terry Guest, who divides his time between this and another plant.

The incinerator was constructed between May 1985 and December 1987 by GKN Birwelco Ltd.. On March 1 it was accepted by GVRD and has operated at or above capacity ever since. The air pollution control package was supplied by Flakt Canada. It is the ninth municipal waste incinerator in the world and the first in Canada to utilize dry lime injection for acid gas control. Emissions are limited to the following:

Particulate:	50 mg/nM^3
HCl:	70 mg/nM^3
HF:	5 mg/nM^3
SO_x:	250 mg/nM^3
Total HC:	45 mg/nM^3

The plant consists of 3 identical process lines each burning 260 metric tonnes per day municipal refuse. The boilers are Babcock & Wilcox waterwall type rated at 86 metric tonnes of steam per hour at 3100 kpa and 248° C each. Burning is accomplished on Martin GmbH inclined, reverse acting, reciprocating grates. Refuse is partially presorted prior to delivery to the plant to remove gypsum wallboard and plastics. The delivered garbage is dumped into the 5247 M^3 bunker for further sorting and feed via grapple to the furnace.

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The furnaces have a minimum operating temperature of 800° C (a permit requirement) and a maximum operating temperature of 930° C (to prevent slagging and ash accumulation on the boiler tubes). The moisture content of the incoming refuse varies between 10 and 25 percent. Exhaust gas from the furnace section gives up heat to the boiler and exits at 200-220° C. to the spray quench/evaporative cooler. Gas flow is 20,000 nM^3/Hr for each line (0° C., 1 atm, 0% H_2O), with an inlet moisture content of 14-16%. The evaporative cooler is a down-flow, co-current unit with residence time of approximately 1.3 seconds. Water is air atomized (100 PSIG) via 5 radially situated spray nozzles at the top of each tower. Droplet size is 80-85μ (design). All introduced water is evaporated prior to exit. Exit temperature is 150-155° C. A hopper is situated at the bottom of the chamber to trap large solids, however it's design is such that it cannot be considered part of the particulate removal system.

Downstream from the evaporative cooler the gas tangentially enters a dry lime adsorber wherein acid gases are removed. This unit consists of an up-flow 3 level chamber with 10-20 second residence time after sorbent injection. Dry Calcium hydroxide powder is fed via two open pipes into the constricted entry to the second chamber. A funnel shaped baffle at the exit from the second chamber prevents direct carryover of the gas entrained sorbent. Heavy sorbent particles fall out and are removed from the bottom of the tower. The smaller particulate continue with the gas flow and are removed in the reverse pulse baghouse downstream.

Total temperature drop over the adsorber and baghouse is approximately 5° C. Partially reacted sorbent captured in the baghouse is recycled via a conditioning silo (residence time: 24 hours minimum) where adsorbed compounds are allowed to migrate to the particle core (absorbed), freeing up sorption sites. Approximately 40% of the total lime feed is recycled powder from the silo. It is air fluidized via 4 screw augers to a high pressure, low volume, 2 inch diameter pipe.

Fresh lime is educted into the sorption chamber via screw auger from a smaller hopper on the top of each chamber. This injection point is also an open pipe without nozzle at the entry to the second chamber. Only minor plugging problems have been experienced. Those noted were attributable to water condensation making the lime "sticky". Lime received on cool, rainy days seemed to cause more problems. Fresh lime feed is currently about 10 metric tonnes per 3 lines per day (7.7 metric tonnes per day design). The lime is 85% passing 200 mesh (85% passing 225 mesh was quoted elsewhere). The available surface area is 19 M^2 per gram (Nitrogen Absorption Test). Stoichiometric ratios are on the order of 2:1.

HCl in the exhaust is monitored along with SO_x Opacity, CO, O_2 by a KVB system (a Perkin-Elmer analyzer provides the HCl continuous analysis). I noted HCl concentrations of 13-19 mg/M^3 at the outlet. Opacity ranged from 2-2.5%. The monitor operates sequentially on each exhaust line for 5 minutes out of each 15. One of those minutes is for purge. The output is recorded on strip charts in the main control room.

Recent tests have been made on the exhaust streams showing up to 91% average removal efficiency on HCl and 60% on SO_x. The results are incomplete as of this date and cannot be released by Montenay. Mr. Boatwright suggested the GVRD should be amenable to providing the data however. Their phone # is (604) 432-6450 in Burnaby.

Dave Moore 12-19-88